Musculoskeletal MRI: Practical Protocols

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Learning Objectives

- Discuss general considerations in designing clinical MRI protocols
- Understand the role of contrast resolution in the context of imaging connective tissues
- Present clinical MRI protocols for MSK MRI at 3.0 T

What is a "Practical" MRI Protocol

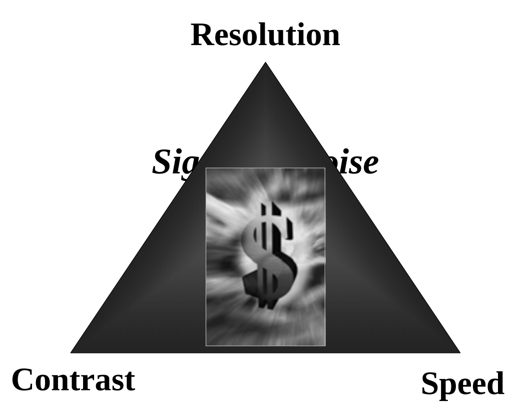
- A practical protocol is not a perfect protocol
- The final product must satisfy many different customers with competing interests
- For every protocol there is a colleague with a better protocol

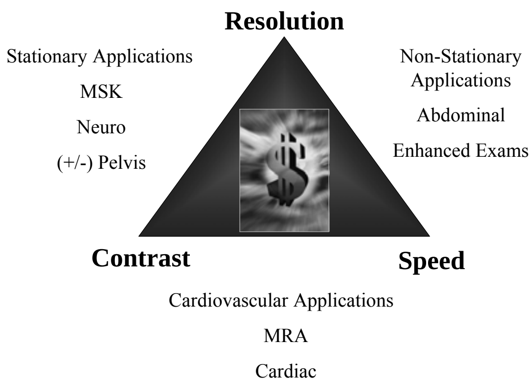
Organizational Guidelines

- Use detailed MRI requests and patient questionnaires to extract sufficient history
  - Mark site of tenderness/mass with fiducial marker
- Use targeted MRI protocols
  - Primary objective
  - Secondary objective
- Limit patient examination times to 45 minutes or less
- Always perform the most important sequence first
- Invest in education for technologists

General Approach for Designing Clinical MRI Protocols

1. Obtain sufficient signal to noise (SNR) to get the job done
2. Optimize contrast for the tissue that you are evaluating
3. Select image plane and resolution based on the anatomy that you are evaluating
4. Adjust acquisition parameters to minimize artifact

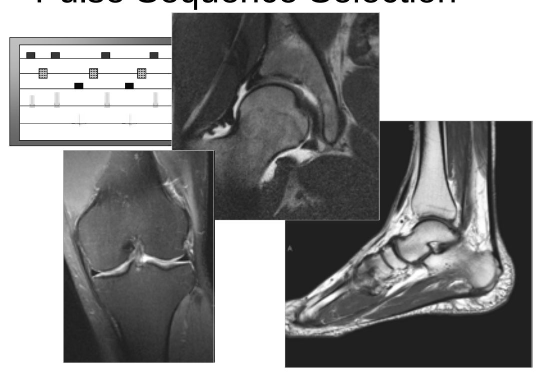




Principle 1: *Musculoskeletal MR imaging protocols are optimized for contrast resolution at the expense of imaging speed*

Optimizing Contrast Resolution

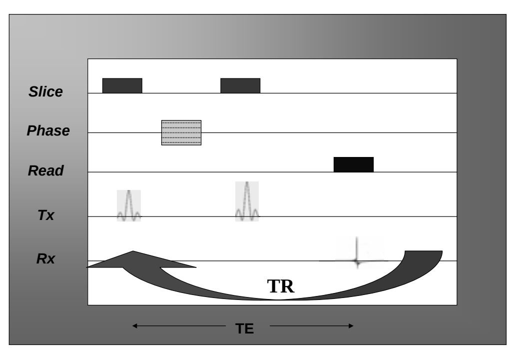
Pulse Sequence Selection



Commonly used sequences for MSK MR imaging

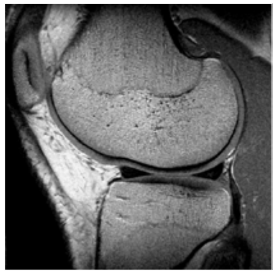
- Conventional spin echo
- Fast (Turbo) spin echo
- Gradient echo

Conventional Spin Echo



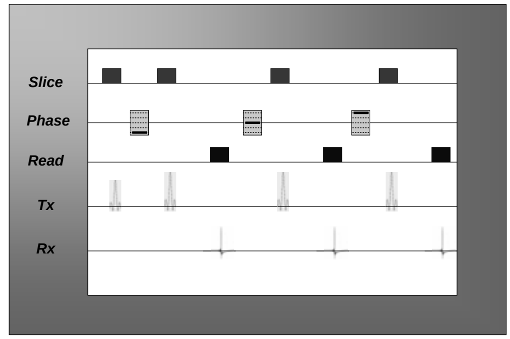
Conventional Spin Echo

- Advantages
  - Excellent contrast
  - Experience
  - Validation studies
- Disadvantages
  - Long imaging times

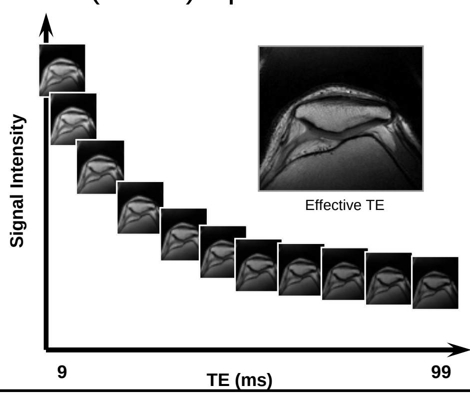


3.0 T Proton density weighted spin echo

Fast (Turbo) Spin Echo

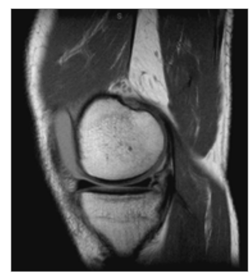


Fast (Turbo) Spin Echo



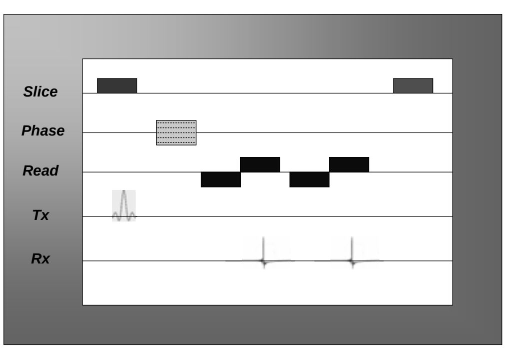
Fast (Turbo) Spin Echo

- Advantages
  - Efficient signal acquisition
    - Fast imaging times
    - Higher spatial resolution
  - Excellent contrast
- Disadvantages
  - Image blurring
  - Magnetization transfer
  - High SAR



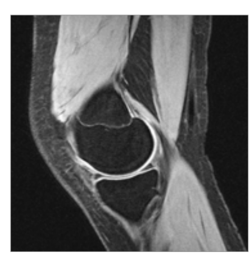
1.5 T Turbo Spin Echo PD-weighted

Gradient Echo



Gradient Echo

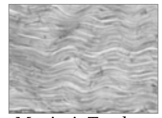
- Advantages
  - Fast imaging times
  - 3D acquisitions are feasible
- Disadvantages
  - Moderate image contrast
  - Prone to artifact
    - Metal artifact

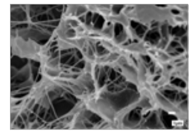


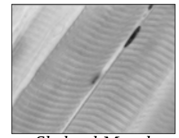
1.5 T Water Excited T1-weighted GRE

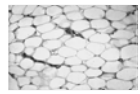
Principle 2: *First optimize contrast based on tissue type, then adjust resolution based on anatomy*

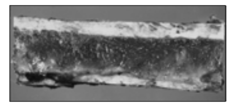
MRI Contrast in MSK Imaging

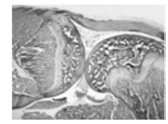

Menisci, Tendons and Ligaments


Articular Cartilage


Skeletal Muscle


Fat


Bone Marrow

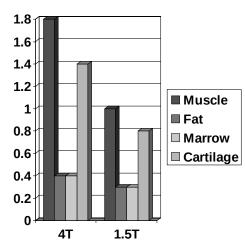

Changes with Maturation

Effect of collagen on tissue contrast

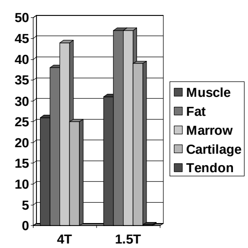
- Efficient spin-spin (T2) relaxation
  - Tissue T2 is inversely related to collagen concentration
  - Tissue T1 is less dependent on collagen concentration
  - Anisotropic arrangement of collagen fibrils produces an orientation dependence of T2 (Magic angle effect)
- Magnetization transfer
  - Collagen is the dominant macromolecular component for magnetization transfer

Field Dependence of Relaxation Times

T_1 (sec)



T_2 (ms)



Duewell SH. *et al. Radiology* 1995; 196:551-555
Fullerton GD et al Radiology 1985; 155:433-435 (*tendon*)

Sequence Selection for MSK MRI

Soft tissues
- Muscle/Fat/Bone Marrow
  - T1 FSE
  - T2 FSE with fat suppression
  - STIR

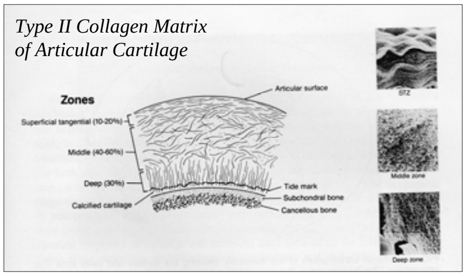
Connective Tissues
- Menisci/Ligaments/ Tendons
  - T1 SE
  - T1 or PD FSE
  - PD FSE with fat suppression
- Articular Cartilage
  - PD FSE with or without fat suppression
  - Fat suppressed T1 spoiled gradient echo

Principle 3: *In evaluation of connective tissue pathology tissue contrast will primarily be determined by:*

Pulse Sequence

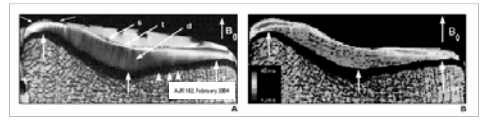
Echo Time

How do tissue properties influence MRI contrast?



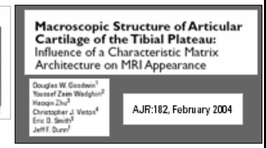
Mow VC, Procter CS, Kelly MA. *Biomechanics of articular cartilage.* In: Basic biomechanics of the locomotor system, Nordin M, Frankel VH eds., pp 31-58 Philadelphia Lea and Febiger.

Effect of collagen on cartilage T2



T2 weighted MRI (7T) Cartilage T2 Map

Freeze Fracture

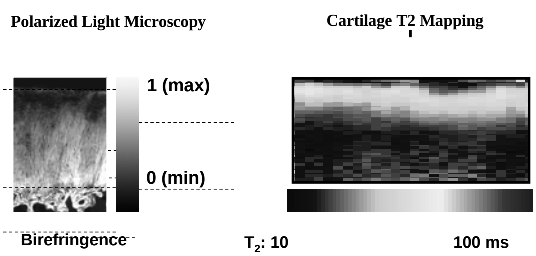


Macroscopic Structure of Articular Cartilage of the Tibial Plateau:
Influence of a Characteristic Matrix Architecture on MRI Appearance

Douglas W. Goodwin
Yousef Zean Wadghiri
Hexiqin Zhu
Christopher J. Vinton
Eric D. Smith
Jeff F. Dunn

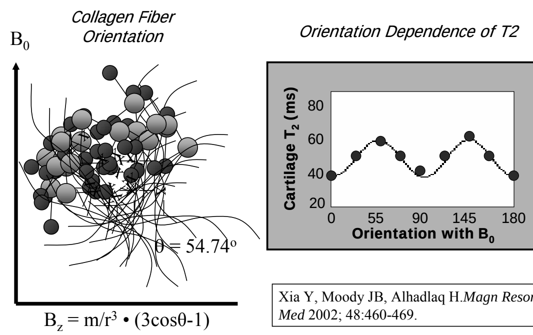
AJR:182, February 2004

Inverse Correlation of Cartilage T2 and Polarized Light Microscopy



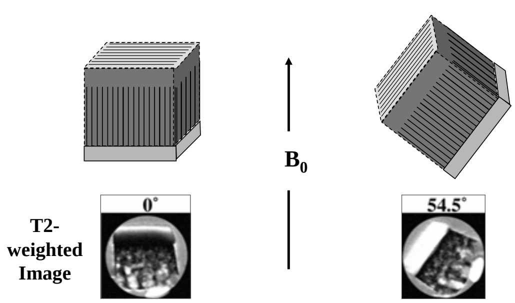
Courtesy of MT Nieminen, Beth Israel Deaconess Medical Center, Boston, MA

The *Magic Angle Effect* in evaluation of connective tissue



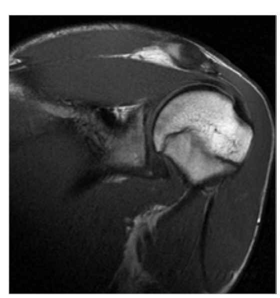
Xia Y, Moody JB, Alhadlaq H. *Magn Reson Med* 2002; 48:460-469.

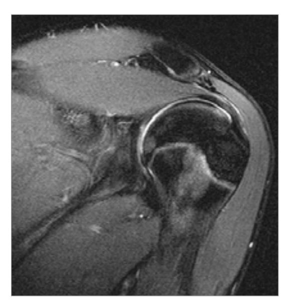
Dependence of Cartilage T2 on Collagen Fibril Orientation



Magic Angle

Magic Angle Effect: *Tendons*





Magic Angle Phenomenon

Tailoring the MRI protocol for evaluation of connective tissues

- Most clinical MSK MRI requests are for evaluation of connective tissue pathology
- Primary indications
  – Shoulder: rotator cuff tear
  – Knee: meniscal tear
  – Ankle: tendon or ligament tear

MSK MRI protocol must be designed to accurately characterize connective tissue pathology, with the critical factor being identification of a surgical lesion (i.e. tear)

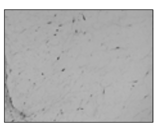
Effect of Connective Tissue Pathology on T2

Normal Tendon

Low concentration of mobile protons

T2 ~ 250 µs

Tendon Degeneration



Mobile proton pool, with high collagen concentration

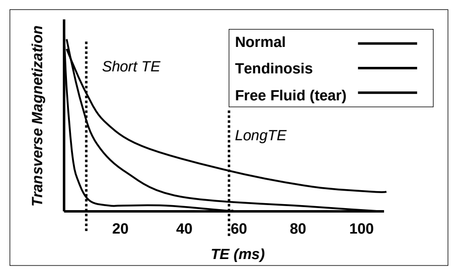
T2 ~ 20 ms

Tendon Tear

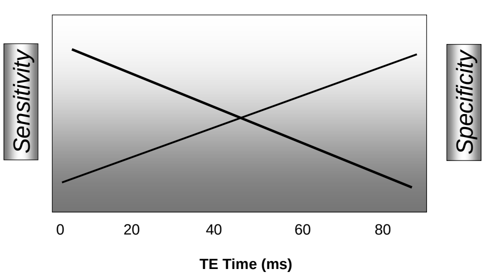
Free Fluid

T2 ~ 100 ms

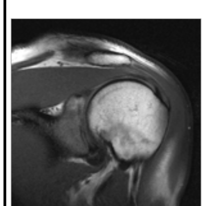
T2 changes with tendon pathology



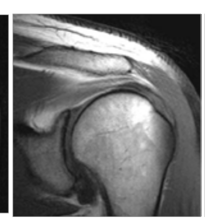
Choice of TE in Evaluation of Tendons and Ligaments



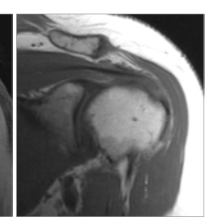
Evaluation of the rotator cuff: *Short TE Sequence*



Normal

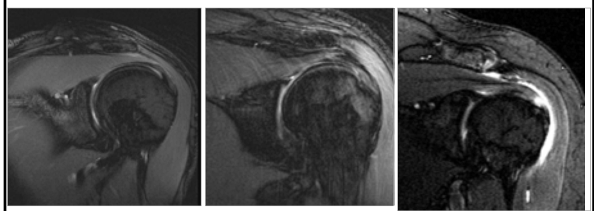


Abnormal



Abnormal

Evaluation of the rotator cuff: *Long TE Sequence*



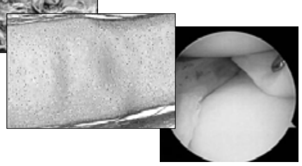
Normal | Tendinosis | Full Thickness Tear

Principle 4: *In evaluation of connective tissues two TE values are often needed:*

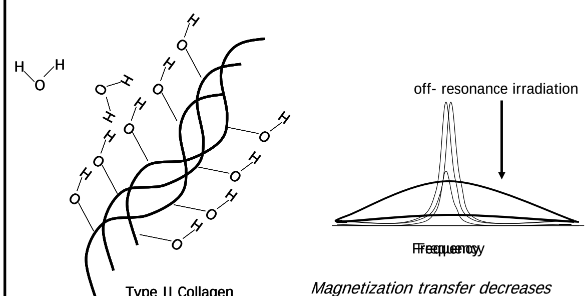
Short TE: high sensitivity, low specificity

Long TE: low sensitivity, high specificity


Magnetization Transfer: *A Probe for Collagen Content*

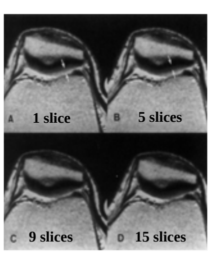


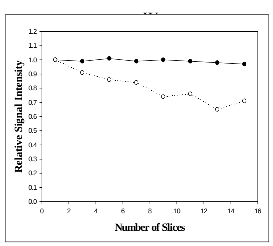
Physics of Magnetization Transfer



Magnetization transfer decreases signal intensity of bound water

Magnetization Transfer With FSE Pulse Sequences





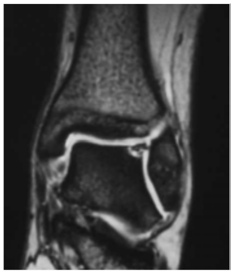
Yao, L, Gentilli A, Thomas A. *Incidental Magnetization Transfer Contrast in Fast Spin-Echo Imaging of Cartilage.* **JMRI**, 6(1),180-184(1996).

Clinical Example: *Effect of Magnetization Transfer on visualization of cartilage*

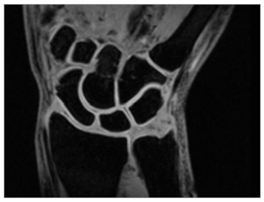
T1-weighted fat suppressed GRE

PD-weighted fat suppressed FSE

Clinical Application of 3D T1-GRE Cartilage Imaging



1.5 T 3D Fat Suppressed T1-weighted GRE



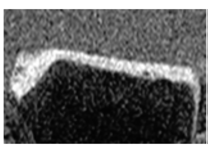
1.5 T Water excited 3D T1-weighted GRE

3.0 T Wrist Imaging

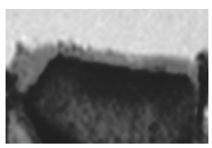
3D Water Excited GRE

Fat Suppressed Proton Density TSE

Contrast versus resolution in visualization of superficial fibrillation



Fat-suppressed 3D FLASH
1mm, 512^2 matrix
0.1 mm^3 voxel size



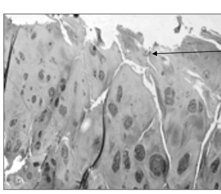
3D DESS
2 mm, 256^2 matrix
1.0 mm^3 voxel size

Improved visualization of superficial cartilage lesion with FSE

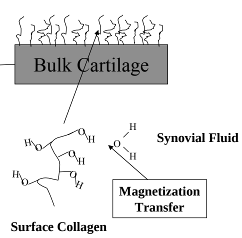
Fat sat T1 -weighted GRE

Fat sat Proton Density FSE

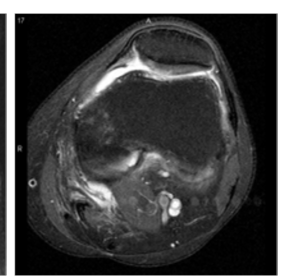
Tissue Contrast at the Articular Surface



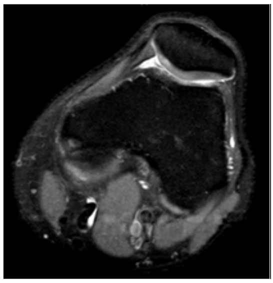
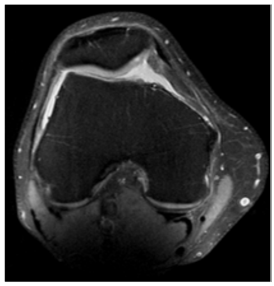
Fibrillated Cartilage



MT improves visualization of the articular surface of cartilage

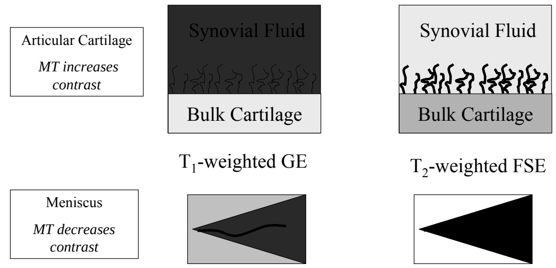


Grade I: Blistering

MRI Findings: Focal elevation in Cartilage T2 with or without superficial fibrillation

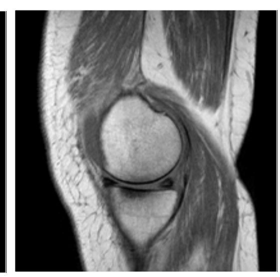
Diagnostic impact of MT depends on tissue type and location



Gradient Echo versus FSE

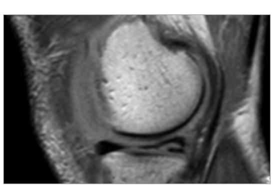
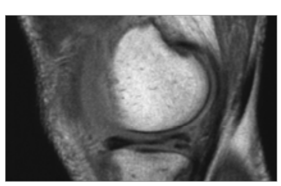

T1-weighted GRE *T1-weighted FSE*

Gradient Echo versus FSE

T1-weighted GRE *T1-weighted FSE*

Conventional SE versus FSE in evaluation of meniscal tear

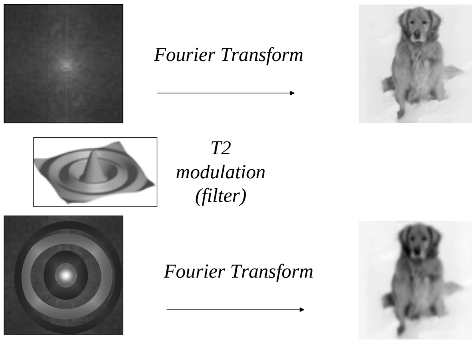



Conventional SE Sequence	TSE Sequence (ETL: 3)
TR: 2000 ms	TR: 2000 ms
TE 20 ms	TE 12 ms

Why are meniscal tears less conspicuous on FSE?

- Magnetization Transfer decreases signal intensity of fluid within tear
- Blurring due to T2 modulation of the point spread function

FSE Blurring

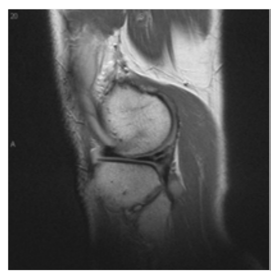


Tips to minimize FSE blurring

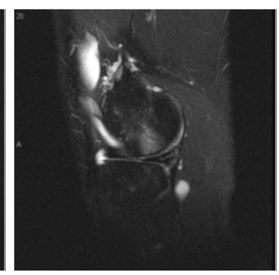
- Reduce the echo train length (< 6)
- Reduce the time interval between echoes (inter-echo spacing)
- Increase spatial resolution
- Less effect on FSE T2 weighted images than on short TE images

Dynamic Range

Use of fat suppression to increase dynamic range of tissue contrast

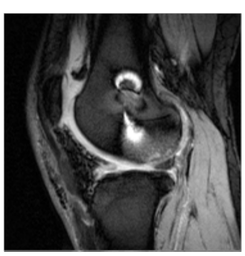


FSE Sagittal PD

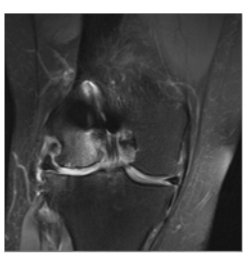


Sagittal PD with fat suppression

28 Year old female with prior ACL repair and knee pain



TR/TE: 2000 ms/15 ms



TR/TE: 2050 ms/30 ms

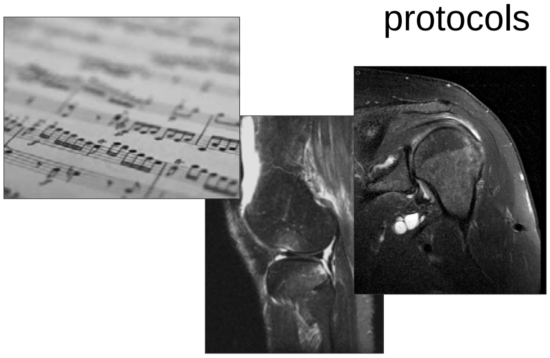
Fat Suppression

3.0 T

Summary of tissue contrast considerations

- Signal intensity changes in connective tissues are dominated by T2 effects of collagen on water
- Magnetization transfer is a critical mechanism of contrast at tissue interfaces
- Short TE is needed to detect changes in the collagen matrix (tendon degeneration)
- Long TE is needed to characterize free fluid (*diagnose tendon tear*)
- Rapid T2 decay results in image blurring with fast (turbo) spin echo sequences
- Fat suppression is useful to increase dynamic range

Composing practical MRI MSK protocols



The Shoulder Protocol

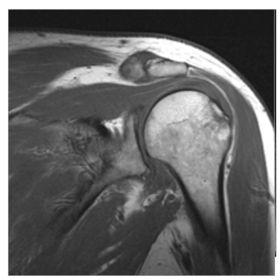
- Primary indication: Rotator cuff evaluation
- Secondary indications
  - – Instability
    - Labrum
    - Capsule
    - Cartilage
  - – Muscles
  - – Marrow
  - – Periarticular soft tissues

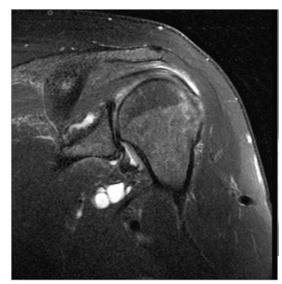
Optimizing TE: *The Shoulder MRI Protocol*

Sequence	TR (ms)	TE(eff) (ms)	ST (mm)	Matrix	FOV (cm)
Axial FSE PD with FS (ET 6)	4000	30	3	512 x 512	18
Coronal Oblique FSE T1 (ET 3)	500	15	4	512 x 512	18
Coronal Oblique FSE T2 (ET 12)	4000	60	4	512 x 512	18
Sagittal Oblique FSE PD	4000	100	4	512 x 512	18

3.0 T Protocol

43 year old male with abduction weakness





The Knee Protocol

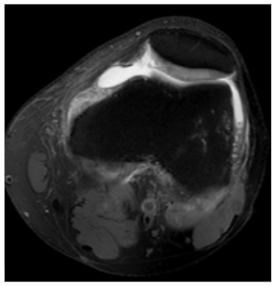
- Primary indication: detection and characterization of meniscal tear
- Secondary indications
  - – Ligamentous injury
  - – Osteochondral pathology
  - – Soft tissue inflammation

3.0T Knee MRI Protocol

Sequence	TR (ms)	TE(eff) (ms)	ST (mm)	Matrix	FOV (cm)
Fat Sat Axial FSE PD with DE (ET 5)	4200	30	3	512 x 512	16
Sagittal FSE PD (ET 5)	2500	15	4	512 x 512	16
Fat Sat Sagittal FSE T2 (ET 6)	5500	45	4	512 x 512	16
Fat Sat Coronal FSE PD (ET 5)	4200	30	4	512 x 512	18

3.0 T Protocol

23 year old with post-traumatic ACL insufficiency

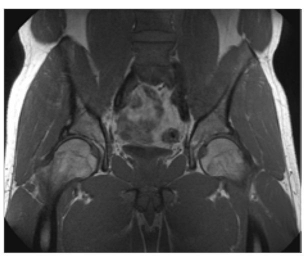


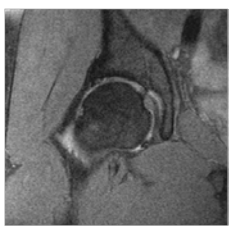
The Hip Protocol

- Primary indication: pain unresponsive to conservative management
  - – AVN
  - – Labral tear
  - – Acetabular femoral impingement
  - – Greater trochanteric bursitis

Problem: Need for large region of coverage with high spatial resolution

29 year old professional hockey player with chronic groin pain



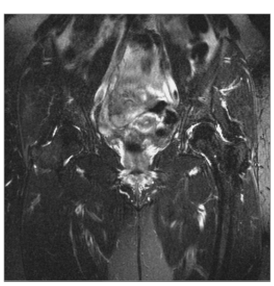


3.0T Hip MRI Protocol

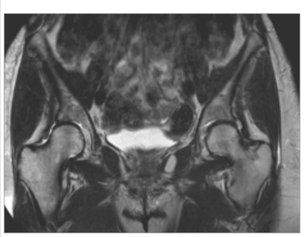
Sequence	TR (ms)	TE(eff) (ms)	ST (mm)	Matrix	FOV (cm)
Coronal FSE T1 (ET 3)	800	12	5	512 x 512	34
Coronal FSE T2 with FS (ET 16)	5500	80	5	1024 x 1024 SENSE factor 2	34
Coronal axial and sagital PD (ET 5)	2000	30	3	512 x 512	16
Coronal PD with fat sat (ETL: 9)	2200	40	3	512 x 512	16

Phased array body coil both hips ***Paired surface coil symptomatic hip***

55 year-old female with left hip and buttock pain with exercise, suspect pyriformis syndrome

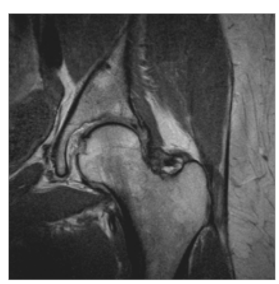


1.5 T Coronal FSE T2, phased array body coil



3.0 T Coronal FSE T2

3.0 T Hip MRI



Coronal PD

Coronal PD with fat suppression

24 year old female soccer player with chronic hip pain

MR Arthrogram requested for suspected labral tear

Take Home Points

- Trade-off of contrast, resolution, and speed
  - MSK protocols optimized for contrast resolution
- Optimize contrast first then adjust anatomy
  - Contrast is tailored for the tissue type
  - Resolution is tailored for the anatomy
- Connective tissue contrast is strongly influenced by collagen
  - Short T2
  - Magnetization transfer
  - Orientation dependence of signal intensity
- Dynamic range is set by fat, use of fat suppression allows shorter TE's to be used to obtain fluid sensitive sequences